Task 3 Report – UHPC Overlay Projects, Material Specifications, and Implementation Issues

Exploration of UHPC Applications for Montana Bridges

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Table of Contents

List of Tables

1 Introduction

Past and current research at Montana State University has been focused on several aspects of ultra-high performance concrete (UHPC). To capitalize on this research, the current research project, Exploration of UHPC Applications for Montana Bridges, is focused on exploring potential future bridge applications of UHPC in Montana. As discussed in the proposal, the MSU research team held an intermediate meeting with the MDT Technical Panel (TP) upon completion of the first two tasks of this current project to present their findings, and to receive guidance from TP regarding the scope of Tasks 3 and 4. The research team and technical panel agreed that proprietary UHPC bridge deck overlays have the most potential for immediate implementation, as current bridge rehabilitation projects in the state are generally concerned with deck repair. The choice of using proprietary UHPC over MT-UHPC was decided based on the facts that MT-UHPC is limited to small batch sizes, and a thixotropic version of the MT-UHPC (required for overlay applications) had not been finalized.

Therefore, Tasks 3 and 4 were modified from the original proposal and are now focused on providing information concerning the implementation of UHPC for bridge deck overlays, and on identifying and testing structural elements in order to quantify the effects that UHPC overlays have on the capacities of existing bridge decks. In summary, the specific updated tasks associated with this research are as follows:

Task 0 – Project Management

Task 1 – Literature Review

Task 2 – Material-Level Evaluation

Intermediate Technical Panel Meeting Task

Task 3 – UHPC Overlay Projects, Material Specifications, and Implementation Issues

Task 4 – Structural Testing

Task 5 – Analysis of Results and Reporting

More specifically, Task 3 focuses on reviewing existing UHPC overlay projects and investigating what other states have learned about using and specifying UHPC for bridge deck overlays. This report documents the work completed as part of Task 3.

2 Summary of Existing UHPC Overlay Projects and FHWA Reporting

2.1 Existing UHPC Bridge Deck Overlay Projects

Proprietary UHPC has been used in bridge-deck overlays by several states. A summary of selected bridge-deck overlay projects is provided in Table 1. In addition to the projects summarized in Table 1, FHWA reported at least 11 other known projects that have been completed across New Jersey, New York, Illinois, Rhode Island, Indiana, Pennsylvania, and Delaware; however, these projects had minimal published information and have therefore been excluded from the table.

Table 1: Summary of Selected UHPC Overlay Projects [1-3]

Project	State	Company	Thickness	Dimension(s)	Volume	Timeline Details
Delaware Memorial Bridge	DE-NJ	UHPC Solutions	Up to 4”	1000’ long	328 yd^3	90 yd^3 at 26’ wide sections in 8-hour shifts
• Used thin lift UHPC paving equipment by GOMACO Corp.						
Bruckner Expressway	NY	UHPC Solutions	2”	--	14 yd^3	9 days and two stages
• Bridge had damaged T beams and UHPC was used to add strength. • Surface was already prepared. • Used crane and concrete bucket to deliver material.						
NJ 159 WB over Passaic River	NJ	UHPC Solutions	2.75”	--	65 yd^3	36 yd^3 in 6-hour stages
• Used Thin Lift UHPC Paver and used two high shear mixers and buggies to deliver. • Removed asphalt and scarified 0.5” of existing concrete deck with Hydrodemolition.						
I-280 WB over Newark Turnpike	NJ	UHPC Solutions	1.5”	340’ long	124 yd^3	Two stages
• Also included a non-thixotropic mix for expansion joint headers. It is not clear if the stated volume includes UHPC for headers. • Overlay was then covered in 2.25” of asphalt per common European practice.						
NJ 57 over Hances Brook	NJ	UHPC Solutions	1.5”	25’ long	6 yd^3	Two stages
• Used stepped longitudinal construction joint with galvanized rebar between phases. • Used a vibratory screed. • Overlayed final with 2.25” of asphalt.						
SR-1 Little Heaven – 2 bridges	DE	UHPC Solutions	1.75”-5” average 3”	120’ long, 42’ wide	96 yd^3	3 casting days in Feb. Over 2 weeks.
• 0.25” Hydrodemolition surface preparation. • Heating accomplished with forced air hydronic systems above and below bridge deck. Also heated UHPC premix and mixing water and tented and heated afterwards. • Varying depths were because of unevenly cambered steel beams. • Reached design strengths of 11-13 ksi in 3 days.						
Bridge over Floyd River	IA	UHPC Solutions Cramer & Associates Inc. Walo Iowa LLC as a sub	1.75”	205’ long, 44’ wide	*48.7 yd^3	Machine placed. Less than 10 workdays. One lane remained open.
• Used a UHPC waffle deck configuration with thin UHPC overlay.						
Mud Creek Bridge	IA	Iowa DOT	1.5”	100’ long, 28’ wide	*13 yd^3	2 separate days with 3 days in between
• Used a regular vibratory screed.						
Bridge No. 7032 in New Mexico	NM	NM DOT	1”	300’ long, 51’-54’ wide	*81 yd^3	105 batches, 0.77 yd^3 each
• Used a non-proprietary thixotropic UHPC mix. • 19.5 ksi. design 28-day compressive strength. Only reached 13.6 ksi – attributed to lack of precise water content control and differences in initial curing temperatures. • Performed direct tension testing on 9 specimens, with 239 psi average. This included 5 epoxy failures, so actual bond strength is larger.						

*Volumes estimated based on available data.

In summary, there were several overarching themes and takeaways from these existing UHPC bridge deck overlay projects. These include the importance of properly performing flow tests to ensure desired material consistency, getting the existing deck to saturated surface-dry (SSD) before casting the overlay, and tarping and/or applying a curing compound soon after placement. Additionally, most projects preferred to install UHPC overlays where the UHPC will be the final riding surface and usually the final surface is diamond ground. When added strength is not a concern, thinner overlays are used to minimize material costs. Thicker UHPC overlays are a good option when bridges need major deck rehabilitation or replacement.

2.2 FHWA Documentation

FHWA [4, 5] summarized the results of previous overlay and repair projects, and developed recommendations for the successful implementation in these applications. Their report first provides overall material specifications for UHPC, and then discusses design and construction specific considerations. The material specifications for the UHPC in these applications are summarized in Table 2.

Table 2: Summary of UHPC Material Properties [4]

Property	Variable Symbol	Acceptance Criteria	Test Method
Compressive Strength	f'_c	18 ksi	ASTM C39 and ASTM C1856
Effective Cracking Strength	$f_{t,cr}$	0.75 ksi	AASHTO T397
Localization Stress	$f_{t,loc}$	$f_{t,loc} \geq f_{t,cr}$	AASHTO T397
Localization strain in direct tension		0.0025	AASHTO T397
Steel fiber reinforcement	V_f	2% by volume – 3.25% for overlays	NA
Rheology/Workability	N/A	Varies by supplier. Typ. hold profile at slope of 10% Ex - Flows of 6 to 8 inches for slopes of 6%	Modification of ASTM C1856 - Dynamic flow table test (20 drops)
Unit Weight	N/A	155 lb/ft^3 (for 2% fibers)	N/A
Chloride Ion Diffusion Coefficient	N/A	2 E-10 in^2/s	N/A
Coefficient of thermal expansion	N/A	7 E-6 inches/inch/°F	N/A
Modulus of elasticity	E_c	2500 $(f'_c)^{1/3}$	N/A
Bond strength to existing concrete	NA	0.35-0.6 ksi	N/A

As discussed above, this document also provides design and construction specific recommendations. For example, it provides recommendations for development length, lap splice length, minimum cover and spacing of reinforcing bars, formwork and traffic vibration mitigation, mixing methods, placement and consolidation, curing, and strength gain. Additionally, recommendations specific to UHPC overlays are discussed, including material consistency, fiber content, thickness, clear spacing, and cover, existing deck concrete substrate preparation, skid resistance, phased construction joints, existing deck surface preparation, placing and finishing equipment and methods, and postconstruction concerns. A complete list of recommendations with pertinent details is included in Appendix A of this report.

3 State UHPC Overlay Material Specifications and/or Special Provisions

While many states have used UHPC in construction applications, only four have developed specifications or special provisions specifically for UHPC overlays (Iowa, New Jersey, New Mexico, New York). This section briefly discusses how the specifications/provisions from these four states vary from or supplement the FHWA recommendations.

3.1 Iowa DOT Special Provisions for UHPC Overlay

One of the primary differences between Iowa [6] and FHWA [4] is a lower required 28-day compressive strength of 14 ksi, compared to 18 ksi from FHWA. Also, their provision specifies compressive testing according to AASHTO T22 instead of ASTM C39/C1856 specified by FHWA. Iowa also includes supplemental material properties, summarized in Table 3.

Table 3: Summary of Material Properties (supplemental to FHWA) included in Iowa UHCP Specification [6]

Property	Acceptance Criteria	Test Method	Frequency
Compressive strength	14 ksi	AASHTO T22	12 tests in 1st day at intervals specified by engineer, 2-day, 3-day, 4-day, 8-day, 14-day, & 28-day
Long term shrinkage	≤ 800 Micro-strain (64 weeks)	AASHTO T160	
Chloride ion penetrability	< 0.1183 lbs/yd^3 (0.5" depth)	AASHTO T256	
Rapid chloride ion penetrability	≤ 350 coulombs	AASHTO T277/ ASTM C1202	2 per job (during field placement)
Scaling resistance	Y < 3	ASTM C672	
Freeze-thaw resistance	Relative dynamic modulus of elasticity > 95% (300 cycles)	AASHTO T161 and ASTM C666A	
Alkali-silica reaction	Innocuous	ASTM C1260	
Slump flow and visual stability	7 inches to 10 inches, no bleed water, consistent fiber distribution	ASTM C1437/ASTM C1611	1 per batch

Compared to FHWA, Iowa provides more specifics on the constituent materials used in the UHPC mix. Specifically, they discuss the requirements for the fine aggregate, cementitious material, steel fibers, water, and admixtures. Also, the provisions specify that the fine aggregates and cementitious materials must be premixed, proportioned in bags/supersacks, and come from the same batch or lot.

Iowa also provides details on including a placement plan with a detailed construction work schedule, which must be reviewed by the engineer and serves as a guide for the contractor to reference. Specific details on what should be included in the placement plan are listed in Appendix B. A preconstruction meeting between representatives of the UHPC manufacturer, contractor, and other interested parties is required to approve the placement plan and no UHPC placement is permitted before this meeting occurs.

Some other notable differences and/or supplemental details that Iowa provides, compared to FHWA, dealing with construction considerations include the following bullets:

- Two UHPC manufacturer representatives are required on site at all times.
- Pumping UHPC is not allowed.

- UHPC must be kept from freezing until a minimum of 11 ksi compressive strength is reached.
- A minimum of three portable batching units are required.
- Finished surface preparation is not allowed until a minimum of 11 ksi compressive strength is reached and a minimum of 3 curing days has occurred.
- The method of UHPC measurement is in square yards of placed and accepted material. Volume is computed using plan dimensions and the grinding quantity is not measured.
- Payment is based on unit price per square yard. Pricing includes surface preparation, supplying, mixing, transporting, placing, finishing, curing, grinding, grooving, and furnishing all equipment tools, labor, and incidentals required.

3.2 New Jersey Performance Specification Section 515 – UHPC Overlay

New Jersey [7] follows many of the same requirements as Iowa [6]. Like Iowa, a placement plan is required, following similar guidelines; however, the New Jersey placement plan also includes sections for quality control of mixing time and batch times, and for cold weather placement procedures, when appropriate. Additionally, similar acceptance criteria to Iowa are followed, but also include the tension criteria listed in Table 4.

Table 4: Summary of Supplemental Material Properties Listed in New Jersey UHPC Specifications [7]

Property	Acceptance Criteria	Test Method
Direct tension cracking strength	≥ 1,100 psi	FHWA-HRT-17-053
Direct tension sustained post-cracking tensile strength	≥ 1,250 psi	FHWA-HRT-17-053
Direct Tension Bond Strength	100% failure in substrate concrete with concrete compressive strength ≥ 4 ksi	ASTM C1583, bonded to exposed aggregate concrete surface
Modulus of Elasticity	≥ 6,500 ksi	AASHTO T256

Some other notable differences and/or supplemental details that New Jersey provides, compared to FHWA and Iowa, dealing with construction considerations include the following bullets:

- Pumping is allowed if it is successfully demonstrated at least 30 days prior to placement.
- Construction joints must be provided at stage lines (including galvanized reinforcement steel), and additional joints are only allowed with prior approval. Additional joints not already approved will not be the basis for additional payment or a time extension.
- Rapid chloride ion penetrability maximum is limited to 250 coulombs.
- The finished overlay surface profile must match the proposed within ±1/4 inch.
- When the UHPC overlay is the final riding surface, a temporary surface above the final grade must be included to facilitate room for diamond grinding.
- At least 60 days prior to the proposed placement, a 4’ x 12’ x 3” rectangular slab must be cast at an 8% grade. Six cores must be taken and have depths within ½” of 3”.

- Because New Jersey also has a performance-based specification, there is a section on qualification testing of 12 cylinders, 3" x 6", for compression following ASTM C39.

3.3 New Mexico Special Provisions for Section 512-B: UHPC Overlay

New Mexico [8] also follows most of the same requirements as Iowa [6] and New Jersey [7], but also provides the supplemental material acceptance criteria summarized in Table 5.

Table 5: Summary of Supplemental Material Properties Listed in New Mexico UHPC Specifications [8]

Property	Acceptance Criteria	Test Method
Flexural strength	Pp/P1 > 1.4	ASTM C1609 with C1856/1856M modifications
Abrasion Resistance	< 0.1 ounces lost	ASTM C944 with C1856 modifications, double load abrasion device, 6" cores
Water/Binder ratio	≤ 0.28	

In addition to some other minor differences, New Mexico specifically specifies using the Ductal product line and the minimum 28-day compressive strength is increased to 18 ksi (matching FHWA [4] recommendations). Some other notable differences and/or supplemental details that New Mexico provides, compared to FHWA, Iowa, and New Jersey, dealing with construction considerations include the following bullets:

- High molecular weight methacrylate (HMWM) should be applied to any unacceptable cracks.
- Multiple meetings are required prior to the placement date to approve similar details to the placement plan discussed above for Iowa, including a mock-up pour.
- The minimum surface roughness is specified at an average height of 0.25".
- Placement requires special approval if the relative humidity drops below 35%.
- Employing the maturity method to determine in-situ strength is allowed using the strength-maturity relationship recommended by the manufacturer. The relationship must be regularly validated and any changes in mix design require a new strength-maturity to be developed.
- The product representatives present at the pours are required to have experience spanning at least 3 years or 5 projects.

3.4 New York Performance Specification Item 578.21010001 – UHPC Overlay

New York [9] follows most of the same requirements as Iowa [6], New Jersey [7], and New Mexico [8]. New York also follows the same 28-day compression strength requirements as New Mexico (and FHWA), with a value of 18 ksi. In addition to some minor material property adjustments, New York also specifies a 24-hour compression strength of 12 ksi and a prism flexural tensile toughness of $I_{30} \geq 48$. The other notable additions that New York provides, compared to FHWA and the other states, dealing with construction considerations include the following bullets:

- The same 4' x 12' x 3" test slab as New Jersey is required for coring.
- A pre-pour meeting is required, but an official placement plan is not mentioned.
- For payment, quantities shall be measured to the nearest cubic foot rather than square yard.

4 Summary

In summary, this task report reviewed existing UHPC overlay projects and related takeaways. The recent FHWA report on UHPC-based preservation and repair methods served as the primary source for this work. Recommendations from this report are compared to those from UHPC-related material specifications/provisions from four state DOTs. Overall, the success that other states have had in using UHPC for overlays is very promising for its potential use in an overlay implementation project in Montana.

5 References

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6. Iowa DOT, *Special Provisions for Ultra High Performance Concrete Overlay. SP-150291*. 2017, BRFN-0`8-3(100)--39-55
7. New Jersey DOT, *UHPC Overlay Research Project. Section 515 – UHPC Overlay*. 2020, No. SW1183790
8. New Mexico DOT, *Special Provisions for Section 512-B: Ultra High Performance Concrete Overlay*, 2021
9. New York DOT, *Item 578.2101001 – Ultra-High Performance Concrete (UHPC) Overlay*, 2018

Appendix A: FHWA Recommendations

The following bullets summarize the specified construction considerations from FHWA [4]:

General UHPC Recommendations

- **Development length**
    - For deformed steel reinforcement No. 8 and smaller, the embedment length should be equal to or greater than the development length, l_d
        - When cover $\geq 3d_b$:
            - $l_d \geq 8d_b$ for reinforcing bars with yield strength $f_y \leq 75$ ksi
            - $l_d \geq 10d_b$ for reinforcing bars with yield strength 75 ksi $\leq f_y \leq 100$ ksi
        - When $2d_b \leq$ cover $\leq 3d_b$
            - Increase minimum l_d by $2d_b$
    - For concrete bridge deck applications, the embedment length of No. 5 deformed bars can be taken as:
        - When cover ≥ 1.25 inches:
            - $l_d \geq 8d_b$ for reinforcing bars with yield strength $f_y \leq 75$ ksi
        - When 1.0 inch $\leq$ cover < 1.25 inches:
            - $l_d \geq 10d_b$ for reinforcing bars with yield strength $f_y \leq 75$ ksi
- **Lap splices**. The lap splice length, l_s
    - $l_s \geq 0.75\ l_d$
    - Clear spacing to nearest spliced bar $\leq l_s$
- **Minimum cover and spacing** of reinforcing bars **s**hould not be less than the greater of
    - 1.5 times the longest fiber length included in the UHPC
    - 0.75 inch

  (Unless adequate fiber distribution is otherwise demonstrated for a specific application.)
- **Formwork and traffic vibration mitigation**
    - Watertight
    - Able to withstand hydrostatic pressures from UHPC and buoyancy forces on any top forms
    - Surfaces should be nonabsorbent (oiled, resin coated, plastic wrapped plywood, steel, etc.) to avoid pulling moisture from the UHPC
    - External vibration from traffic and removal of formwork should be avoided until 14 ksi strength is achieved

- **Mixing**
    - Batch and mix according to developer or manufacturer recommendations
    - Store materials and mix water at reduced temperatures
    - Target higher end of flow range for hot weather, and lower end of flow range for cold weather
    - Mixer should be capable of dispersing liquids and fibers uniformly. Typically, most concrete or grout mixers can be used for mixing, but at one-third to two-thirds the volume.
    - Temperature of UHPC at end of mix should be kept between 40 and 80 °F. Ice can be used to replace some or all mix water.
- **Placement and consolidation**
    - Fresh UHPC should be transported, placed, and covered as soon as possible.
    - Thixotropic UHPC should be vibrated as necessary for good consolidation though constituent segregation should be avoided.
- **Curing and strength gain**
    - Should be protected from freezing until minimum 14 ksi compressive strengths
    - Exposure to the external environment should be avoided until specified minimum strength is achieved. This can be achieved through a combination of conventional concrete curing compound and plastic sheeting.

UHPC Overlay Recommendations

Most points discussed above for general UHPC recommendations apply to UHPC bridge deck overlays and additional points specific to overlays are listed here:

- **Material consistency**
    - Thixotropic such that it can be placed without top forming
- **Fiber content**
    - Should be based on mechanical properties for strength and serviceability objectives; however, most overlays to date used 3.25% by volume
- **Thickness, clear spacing, and cover**
    - Minimum finished overlay thickness should be the greater of
        - 1.0 inch
        - Or 1.5 times the max fiber length
    - Minimum nominal clear cover after finishing and profiling over reinforcing bars should be 0.625 inch

  - Minimum clear distance between reinforcing bars and existing concrete deck substrate should be greater of 0.5 inch or the maximum fiber length

- **Existing deck concrete substrate preparation**
  - Concrete substrate should be roughened to a minimum profile of 0.125 inch, measured as the average value between peaks and valleys or equivalent to a roughness average (Ra) of 0.0625 as defined by ASME B46.1.
  - Substrate surfaces should be roughened with both macro- and micro-texture to enhance the bond strength. Micro-texture is more important for tensile bond strength and is best achieved by removing the cement paste. Macrotexture is more important for shear strength.
  - UHPC to UHPC can be bonded with set retarders to expose the fibers.
  - Prewetting concrete to SSD is very important and typically requires a minimum of 6 hours or more of continuous wetting.
  - Bonding agents can be considered, although no long-term data on performance has been gathered.
- **Skid Resistance**
  - Completed surface must provide adequate skid resistance. The desired surface is typically achieved through grinding the entire surface. Texturing the surface is also allowed; however, skid resistance must be validated, such as with ASTM E303.
- **Phased construction joints**
  - Construction joints should be detailed to maximize bond, minimize water, and provide mechanical continuity. Joints should be reinforced if placed in negative bending region. May not be necessary if existing deck reinforcement is fully encapsulated in UHPC. UHPC fibers should be exposed.
- **Existing deck surface preparation**
  - For deep removals or areas that are heavily patched, scarifying should be performed first for a uniform removal, then followed by Hydrodemolition or sand blasting. Hand chipping should be avoided (to avoid microcracks), but when necessary limited to a hammer size of 35 pounds maximum.
- **Placing and finishing equipment and methods**
  - Conventional concrete deck screeds can be used to spread, consolidate, and finish overlays less than 2 inches; however, if a thixotropic mix is used, the placement still requires significant assistance in distributing the material evenly before a pass is made with the screed.
  - Automated bridge deck finishing machines designed specifically for UHPC have been used on numerous overlay installations in the United States and should be considered for

thixotropic mixes. This is because conventional concrete bridge deck finishing machines have issues with the UHPC sticking to the augers and rollers and UHPC surface tearing.

- **Postconstruction concerns**
    - Exposed fibers should not be a concern. Fibers have not shown to cause any damage to vehicles, pedestrians, or animals. Over time the fibers will rust. Eventually the fibers and rust will disappear.

Appendix B: Placement Plan

The following text is directly from the Iowa Special Provision for UHCP Overlays [6], detailing the placement plan.

1. Submit a Placement Plan with a detailed construction work schedule to the Engineer for review and approval at least 30 days prior to the scheduled UHPC placement pour. The following list is intended as a guide and may not address all of the means and methods the contractor may elect to use. The Contractor is expected to assemble a comprehensive list of all necessary items for executing the placement of UHPC.
    - Responsible personnel and hierarchy.
    - Equipment – including but not limited to mixers, holding tanks, generators, wheelbarrows, scales, meters, thermometers, floats, screeds, burlap, plastic, heaters, blankets, etc.
    - Quality Control of batch proportions - including dry ingredients, steel fibers, water and admixtures.
    - Quality Control of mixing time and batch times.
    - Batch procedure sequence.
    - Form work – including materials and removal.
    - Placement procedure – including but not limited to surface preparation of existing concrete surfaces and pre-wetting of the existing concrete interface to a saturated surface-dry (SSD) condition before the placement of UHPC), spreading, finishing, and curing protection. Include provisions for acceptable ambient conditions and batch temperatures and corrective measures as appropriate.
    - Threshold limits for ambient temperature, ambient relative humidity, batch consistency, batch temperature, batch times and related corrective actions.
2. A preconstruction meeting will be held between the UHPC manufacturer's representative, the Contractor's staff, and representatives from Iowa DOT District Office, Office of Bridges and Structures, and Office of Construction and Materials to review the Contractor's Placement Plan prior to placement of UHPC materials. No UHPC pour will be permitted until the aforementioned Placement Plan has been submitted by the contractor and approved by the Engineer.
3. Pumping of UHPC is not allowed.
4. Construction loads applied to the bridge during UHPC placement and curing are the responsibility of the contractor. Submit the weight and placement of concrete buggies, grinding equipment or other significant construction loads for review as part of the proposed Placement Plan.